Present status of the new cosmic-ray experiment EMMA

P. Kuusiniemi[1], T. Räihä[1], J. Sarkamo[1], T. Enqvist[1], J. Joutsenvaara[1], T. Jämsén[2], P. Keränen[3], H. Laitala[1], M. Lehtola[1], A. Mattila[1], J. Narkilahti[1], J. T. Peltoniemi[1], A. Pennanen[1,4], M. Roos[5], C. Shen[1], W. Trzaska[4], I. Usoskin[2], M. Vaittinen[1] and Z. Zhang[1]
[1]Centre for Underground Physics (CUPP), University of Oulu, Finland
[2]Sodankylä Geophysical Observatory, University of Oulu, Finland
[3]Radiation and Nuclear Safety Authority - STUK, Helsinki, Finland
[4]Department of Physics, University of Jyväskylä, Finland
[5]Department of Physical Sciences, University of Helsinki, Finland
Email: Pasi.Kuusiniemi@oulu.fi, Tomi.Raiha@oulu.fi

***Abstract*— The EMMA set-up (Experiment with MultiMuon Array) will measure high-energy muons resulting from cosmic-ray air showers. The aim is to deduce the chemical composition of primary cosmic particles around the knee energy. The experiment will be built underground to a depth of 85 m in the Pyhäsalmi mine, Finland, and its construction is expected to be completed by the end of 2007.**

I. Introduction

The flux of high-energy cosmic rays decreases substantially at the so-called knee energy around 3 PeV. The composition and origin of the cosmic-ray primaries are poorly understood at and particularly beyond that energy. The underground measurement of high-energy muons produced in air-shower cascades may increase our understanding on cosmic-rays at the knee region.

II. Physical background

The muon lateral density distribution is sensitive to the energy and mass of the primary cosmic-ray particle. As shown by CORSIKA+QGSJET 01 [1] simulations with an 50 GeV muon energy cut-off in Fig. 1, the muon density at the shower core and the density gradient can be used to estimate the energy and mass of primary cosmic-rays, respectively.

As high-energy muons originate close to the first interaction they carry essential information about the primary particle. Therefore the measurement of lateral density distribution of high-energy muons provides a competent way to study the composition around the knee.

III. EMMA

The Experiment with MultiMuon Array (EMMA) [2] is designed to measure the multiplicity and the lateral density distribution of high-energy muons. This will be carried out using an underground array of muon detectors.

The detector array is placed at a depth of 85 metres in the Pyhäsalmi mine (owned by Inmet Mining Corporation, Canada), Finland. This depth corresponds to 240 m.w.e and it provides an approximately 50 GeV muon energy threshold. In order to reduce construction costs EMMA is placed in already existing caverns of the mine.

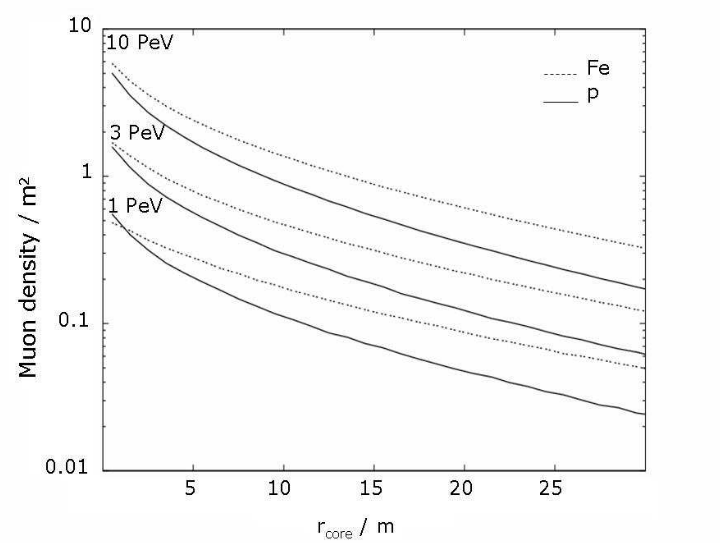

Fig. 1. The lateral density distributions of high-energy muons of proton- and iron-initiated air-showers at 1, 3 and 10 PeV energies simulated using CORSIKA+QGSJET 01 [1] and an 50 GeV muon energy cut-off corresponding to a depth of 85 m.

A. Detectors

EMMA employs former DELPHI barrel muon chambers (MUB) [3]. The detectors (Fig. 2) are gas-filled and position sensitive with an area of approximately 2.9 m^2 each. They consist of seven half-overlapping chambers, most having an active volume of $365 \times 20 \times 1.6$ cm^3. Each chamber provides three timing signals which can be used to extract positions of passing muons.

Due to safety issues a non-flammable gas mixture of $Ar : CO_2$ with a respective ratio of approximately $92 : 8$ is used without formerly used CH_4. This has a minimal effect on the total efficiency but it slightly worsens the position resolutions of the chambers which are, however, still within 2 cm. The detectors are currently being tested (gas-leakage and HV) as well as re-calibrated (efficiency, drift-velocity, etc.) due to the

Fig. 2. Detectors arranged for testing. They were transported from CERN to Pyhäsalmi in November 2005.

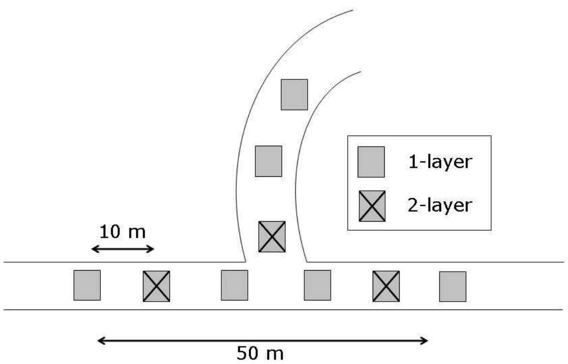

Fig. 3. Layout of EMMA in the mine caverns at 85 m.

changed filling-gas mixture.

B. Layout

On the basis of Fig. 1 two straightforward conclusions concerning the lateral distribution measurements can be drawn: i) the shower core must be located as accurately as possible and ii) the density gradient must preferably be measured within tens of metres. In order to fulfill these tasks with the available detector area of approximately 150 m^2 EMMA is built up of nine detector units with an area of approximately 15 m^2 each and mutual distances of approximately 10 metres. The schematic layout of EMMA is illustrated in Fig. 3.

In order to maximize the detector area and quality of data EMMA employs two different kinds of detector units. Single-layer units (Fig. 4) have five detectors placed horizontally side-by-side and double-layer units (Fig. 5) consist of two layers of five detectors, which are on top of one another 2.5 m apart.

While single-layer units are only for counting muon hits in the detectors the double-layer units are needed to determine the shower axis (angles). The latter is essential information for the shower reconstruction. This procedure is carried out using

Fig. 4. One single-layer unit of EMMA hosting five detectors. The housing shields the detectors and related electronics from high-humidity atmosphere of the mine.

Fig. 5. Construction of the first two-layer unit of EMMA. Note 1 : 7 incline of the cavern floor and roof.

muon tracking, i.e. by connecting muon tracks in two separate layers of position sensitive detectors. With the above given numbers the angles can be determined within one degree.

It is also worth noticing that the detector unit housings provide a practical and cost efficient way to shield the detectors and related electronics from the high-humidity atmosphere of the mine.

IV. Shower reconstruction

As can be easily imagined measured muon positions can be used to estimate the shower axis and density distribution of a given air-shower. As an example Fig. 6 shows simulated muon positions of one 4 PeV proton-induced air-shower hitting close to the centre of EMMA array.

In the present simulations the lateral density distribution of high-energy muons (see Fig. 1) is parametrised as

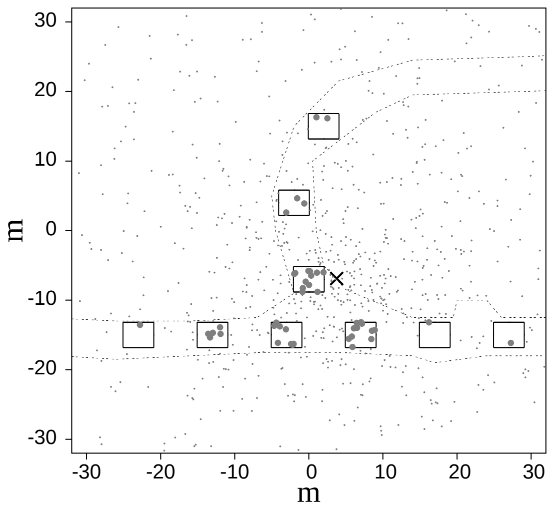

Fig. 6. The detector units (squares), simulated muons from one 4 PeV proton shower (small dots) and detected muons (large dots) together with the shower axis position (cross).

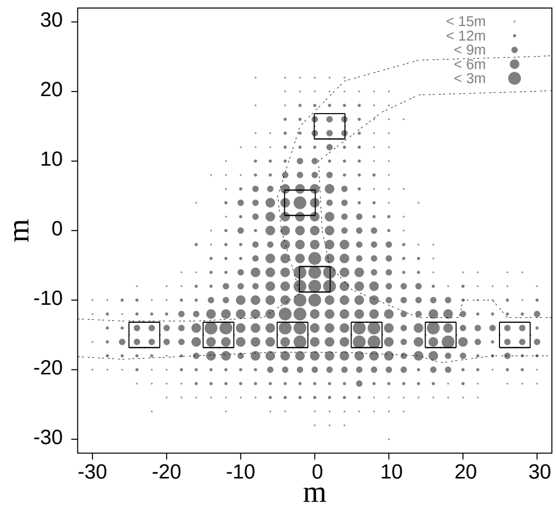

Fig. 7. Average shower axis reconstruction uncertainties for 4 PeV proton showers.

$$\rho(r) = \frac{N_\mu}{2\pi \times 0.11 \times R_0^2} \times \left(\frac{r}{R_0}\right)^{-0.4} \times \left(1 + \frac{r}{R_0}\right)^{-5} . \quad (1)$$

Here r is the distance from the shower axis, N_μ is the total number of muons and R_0 is related to the density gradient of the distribution. The shower reconstruction is carried out by fitting the above function to the muon hit data. The fit results in the shower axis position and the density distribution for each shower.

A somewhat obvious result is that the reconstruction accuracy of the shower axis position depends on the shower axis position and it is at its best close to the central area. This is illustrated in Fig. 7 in which the uncertainties on the average shower axis reconstructions are plotted. Thus, on the basis of our simulations EMMA is able to reconstruct the shower axes and lateral distributions within approximately 300 m^2. This indicates that EMMA has good composition determination capabilities, as recently discussed in [4].

During detector testing and installation we will further improve our data analysis methods concerning, for example, muon tracking and muon scattering effects in the rock overburden.

V. Schedule

EMMA is under construction. The first detector support together with its housing is installed in to the cavern. The first detectors (one third of the array) are expected to record data in early 2007. At that point the array is already sufficient to record, for example, possible high muon-multiplicity events observed at CERN (see [5] and references therein). After the first phase is completed EMMA will be expanded gradually and it is expected to be fully operational by the end of 2007.

Acknowledgment

The support from the Magnus Ehrnrooth Foundation, the Jenny and Antti Wihuri Foundation, the Finnish Academy of Science and Letters (Väisälä Foundation), and the Finnish Cultural Foundation is acknowledged. The work is funded by the European Union Regional Development Fund and it is also supported by the Academy of Finland (projects 108991, 7108875 and 7106570).

References

[1] D. Heck *et al.*, Report FZKA 6019, 1998.
[2] T. Enqvist *et al.*, astro-ph/0512398.
[3] P. Aarnio *et al.*, Nucl. Instrum. Methods A303 (1991) 233.
[4] T. Enqvist *et al.*, Proc. CRIS 2006, Catania, Italy (to be published in Nucl. Phys. B (Proc. Suppl.)).
[5] J. Ridky *et al.*, Nucl. Phys. B (Proc. Suppl.) 151 (2006) 310.